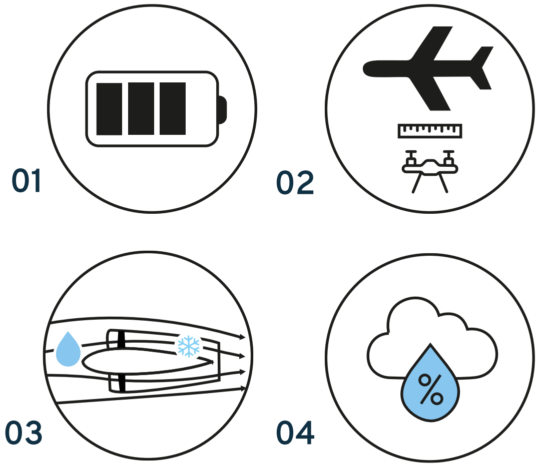
GLOBAL ICING REPORT

for Air Taxi Services

Examining 30 UAM Cities

UNISPHERE

WHY WE THINK IT IS ESSENTIAL *TO BETTER UNDERSTAND* ICING CONDITIONS



First, as the name implies, eVTOLs are **electrically powered**, which has certain drawbacks. Because **batteries have a lower energy density** than kerosene, eVTOLs tend to be low on energy. As a result, most are **not equipped with de-icing systems** because (a) it adds weight, which limits the aircraft's range, and (b) the system itself requires energy, which is limited anyway.

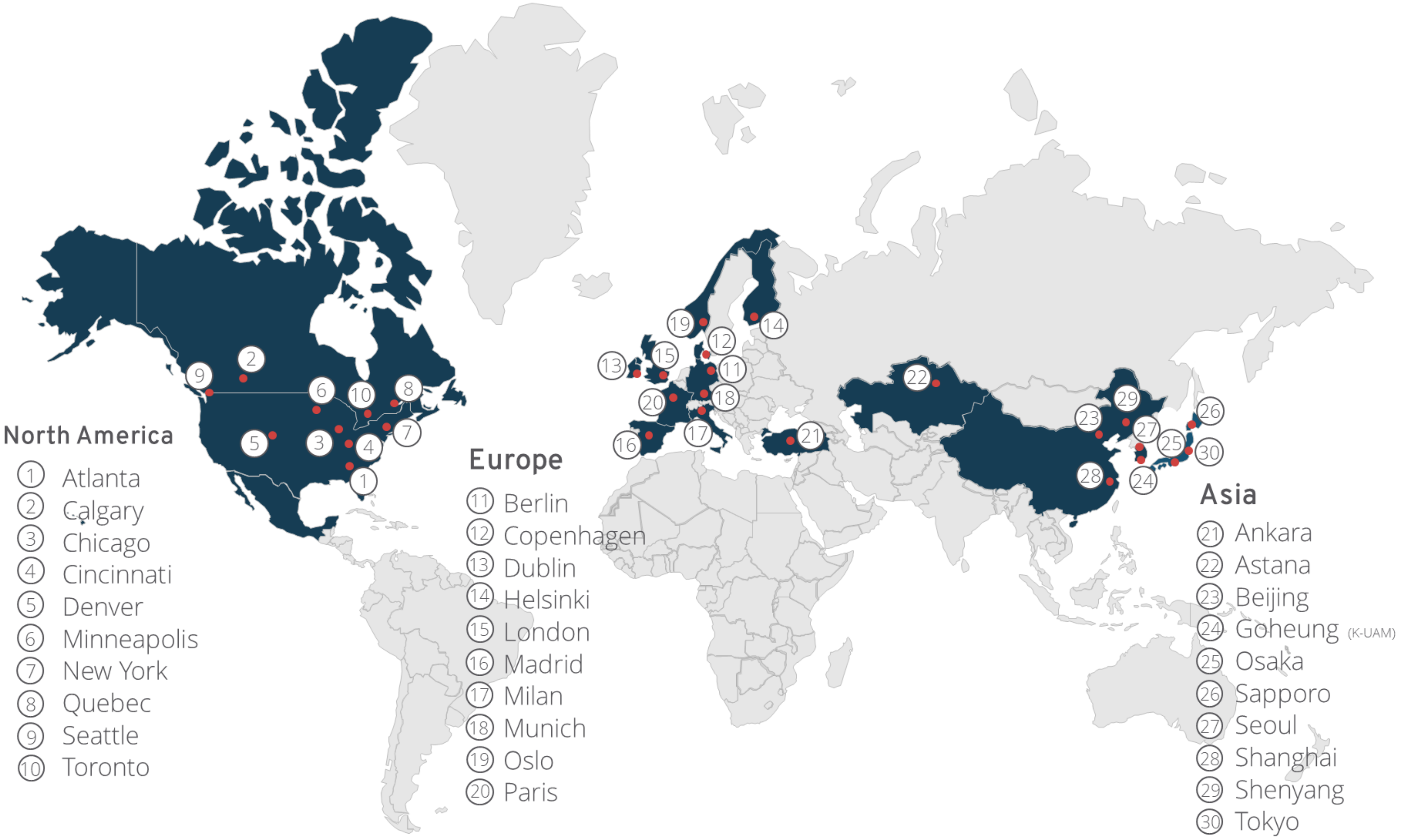
Second, eVTOLs are **smaller than commercial aircraft**. Because of the smaller size, icing that forms on the airframe has a **greater impact** than we are used to from conventional aviation. In other words, 1 cm of ice on an eVTOL has a much greater impact on aerodynamics than on an airliner. As a result, the pilot has less time to react to icing, making the eVTOL more sensitive.

Third, due to aerodynamic effects in the area of the propulsion system (rotors), **icing effects** occur at **temperatures above zero degrees Celsius**, caused by the fact that the **rotors generate a low pressure** that can lead to a **drop in temperature**. Similarly, icing can occur on the aircraft at, for example, 2 degrees Celsius and high humidity.

Fourth, eVTOLs are planned to be **operated at lower altitudes**. At these altitudes, the temperature is more moderate than at high altitudes. Because **warmer air can contain more moisture** in absolute terms, severe icing is more likely to occur than at altitudes where airliners operate.

Due to these characteristics, which are based on the **aircraft design** and **concept of operations**, **eVTOLs are more sensitive to icing conditions**, which motivated us to conduct this study on the impact of icing on overall service availability in different regions of the world.

Study scope – analyzing 30 cities on their icing conditions



The global report covers a selection of 30 cities around the world, which are active in the field of Urban Air Mobility or have been voted as being of interest in our interaction with the eVTOL community.

Within each city, the study used the location of the main train station since they represent a connecting point for mobility and a uniform selection could be made for all 30 cities. The exact location coordinates are listed in the appendix.

Method and results

Next, we will provide insights into the icing conditions of the 30 cities studied in this whitepaper. For each region, we provide a separate overview of the icing conditions over the course of a year.

The general overview will be followed by a more detailed breakdown that focuses on the time of the year when icing conditions can occur at the respective location, providing a deeper understanding of the seasonal impact.

Additional analysis types focus on covering higher altitudes and comparing daytime and nighttime effects.

Method to derive the results

For the analysis, historic weather model data from different weather models were used. Using weather models instead of weather recorded with weather stations has the advantage, that it gives the flexibility to (a) study every coordinate on the globe and (b) analyze weather parameters at any given altitude. Icing conditions were identified based on analysis of low temperature (T) and high relative humidity (RH) combinations.

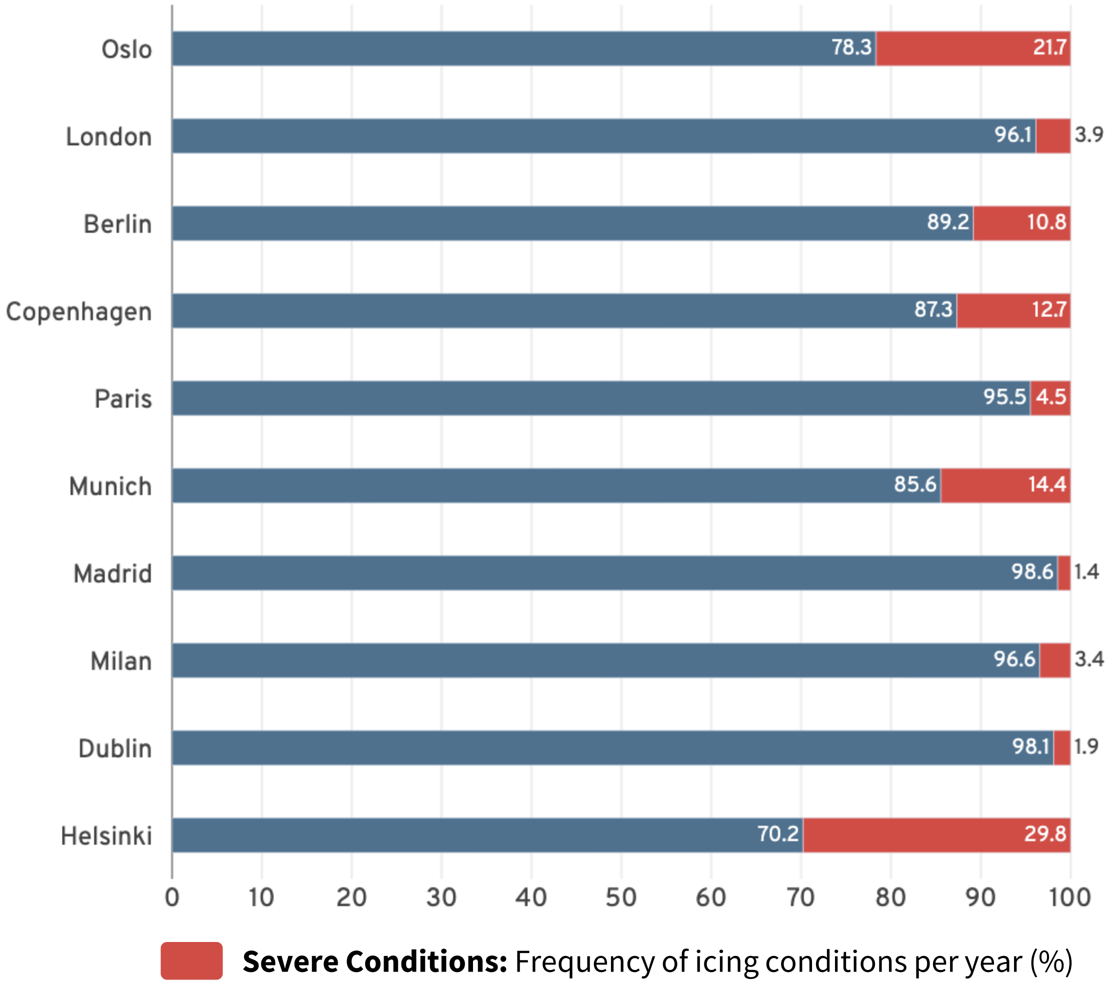
Analyzing different altitudes is in particular of relevance for icing conditions due to temperature decrease at altitudes, which can lead to icing impact while flying that is not observed at ground level.

For the 30 cities, icing conditions were analyzed at the surface (7 feet), 500 ft., and 1500 ft. The advanced analysis covers surface, 500 ft., 1000 ft., 2000 ft., 3000 ft., and 5000 ft. to gain a more granular understanding.

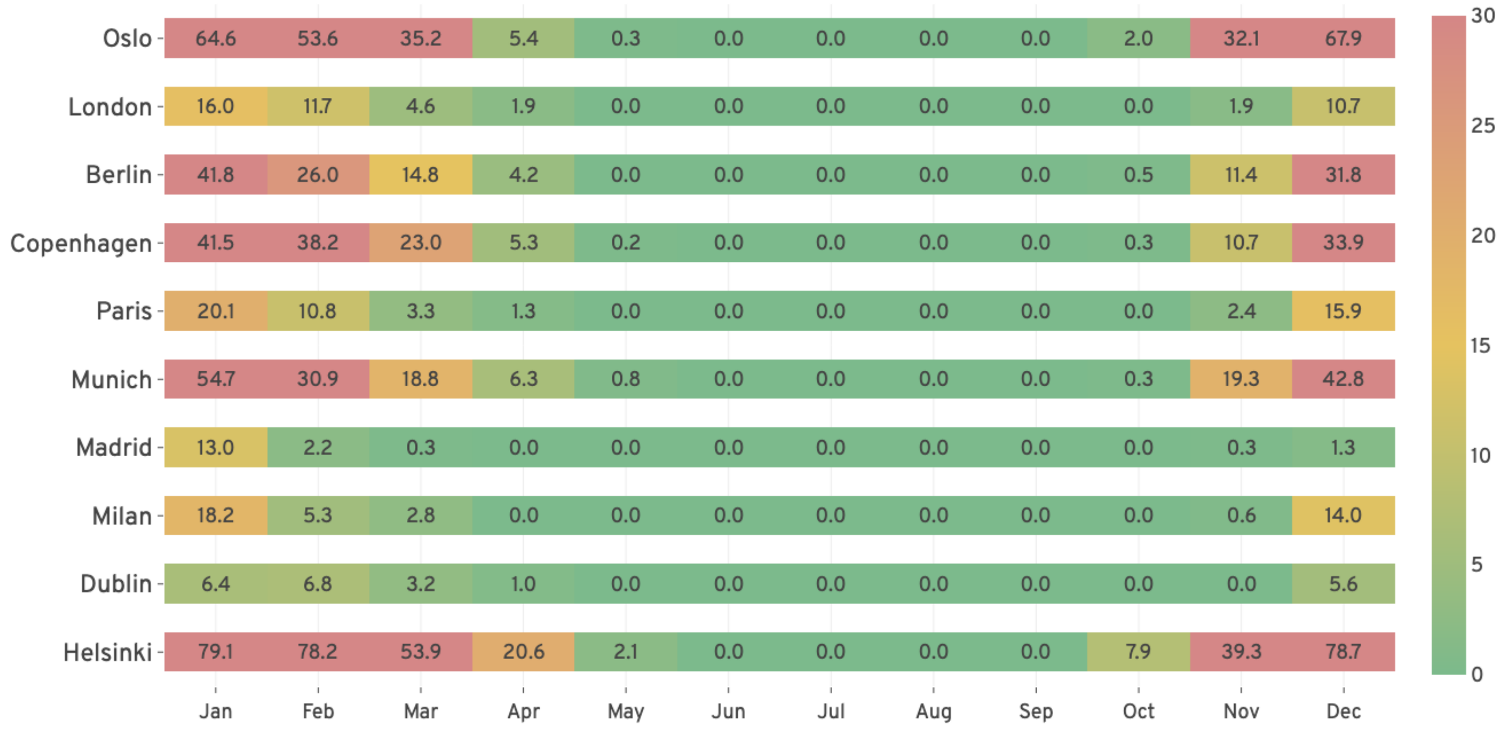
For comparing daytime and nighttime, the sunrise and sunset of the specific day was considered to ensure that seasonal difference in the time of daylight hours are covered in the analysis.

Overview of the icing conditions in Europe – overall impact of icing conditions

- Strong increase in icing conditions from south to northern Europe visible when considering the altitudes surface (7ft), 500 ft, 1500ft.
- Despite its rather southern location in Europe Munich reveals relatively high percentages of yearly icing conditions (14%).
- Highest frequencies of icing evident in Helsinki and Oslo with up to a third of the yearly hours.
- London, Dublin, and Paris show rather low percentages of icing conditions at the analyzed altitudes likely associated with the influence of the North Atlantic Current and their vicinity to the sea.



Overview of the icing conditions in Europe – comparing seasonal impact

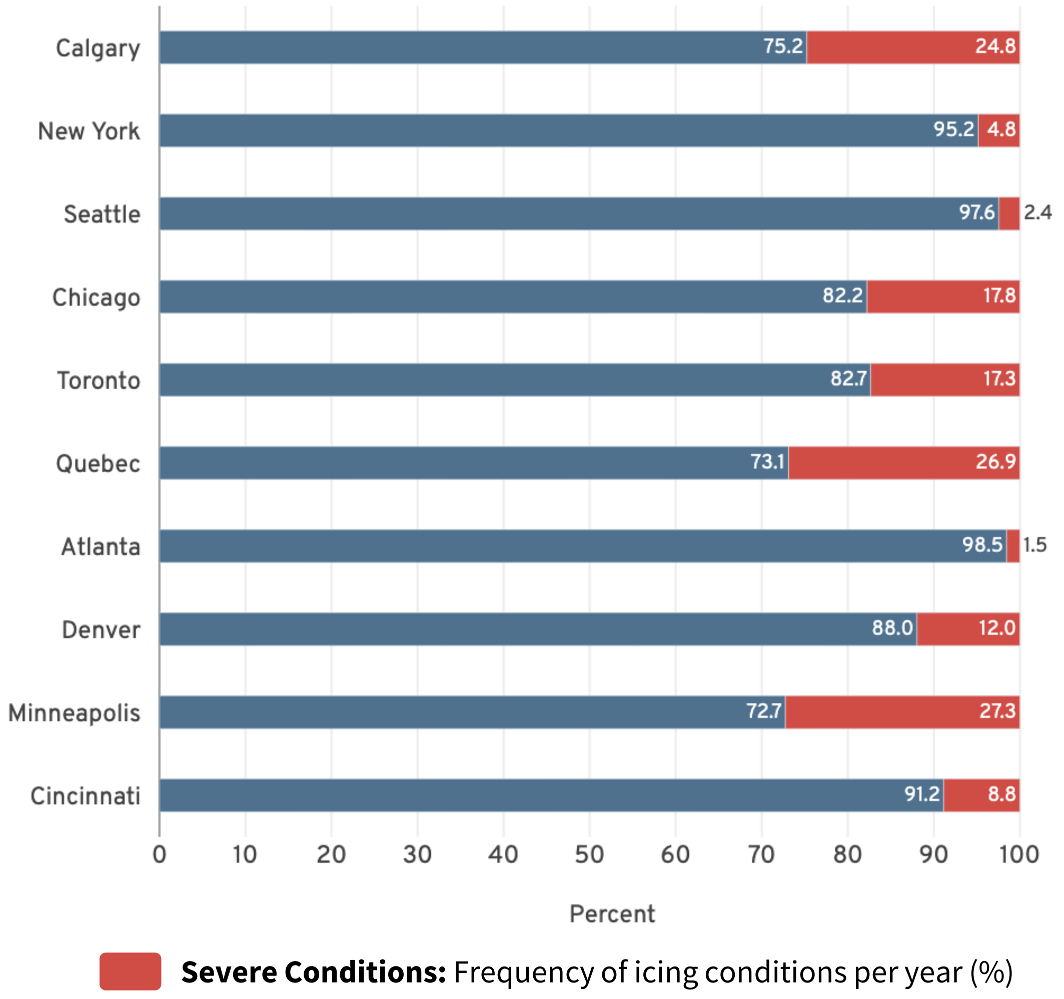


Frequency of icing conditions per month (%)

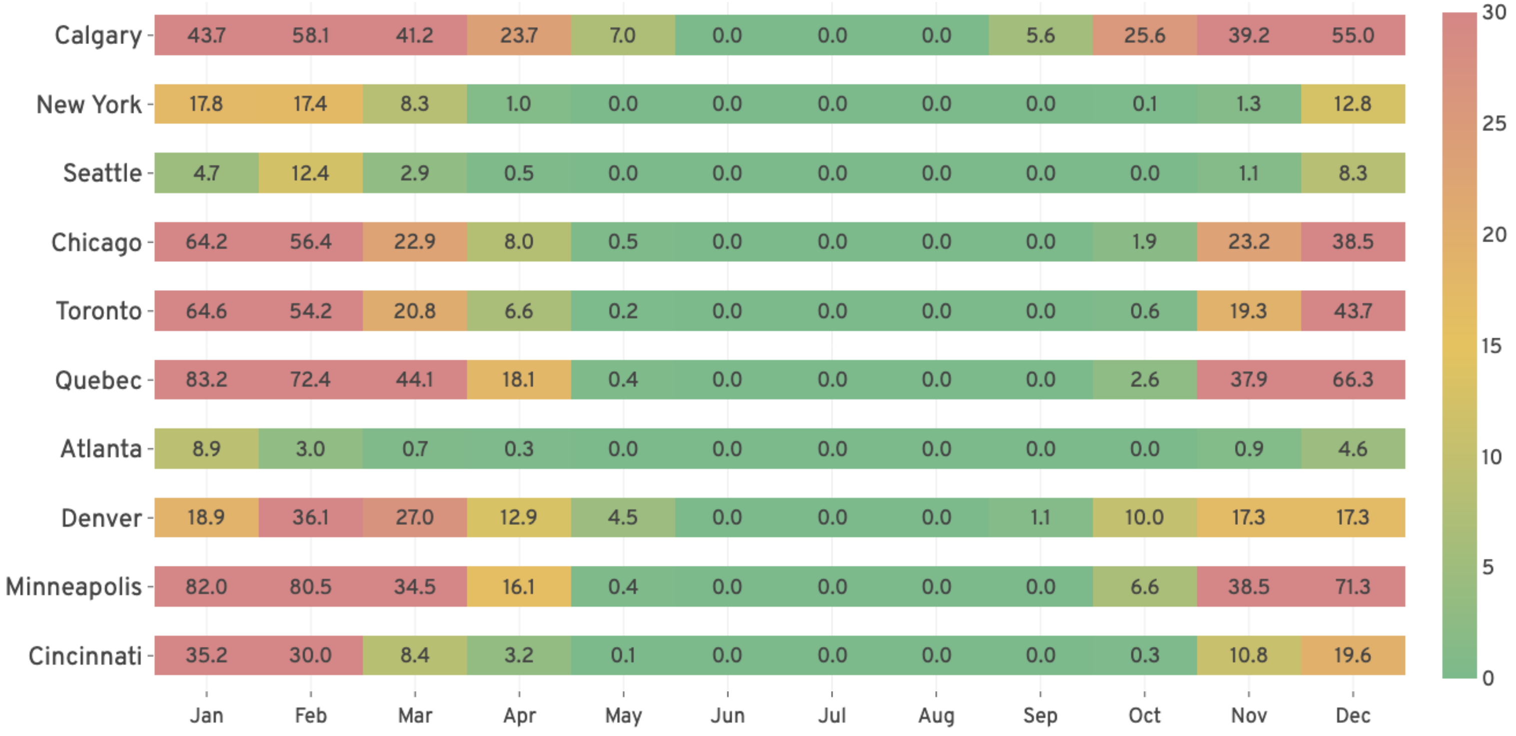
- Strong impact of icing from December to February visible for most of the analyzed European locations.
- From May to September icing conditions rarely occur at the analyzed altitudes for all European cities.
- Helsinki shows a relatively short window without any icing potential from June to September.

Overview of the icing conditions in North America – overall impact of icing conditions

- Calgary, Minneapolis, and Quebec are most impacted by Icing when considering surface (7ft), 500 ft, and 1500ft for the ten analyzed locations in North America.
- Atlanta, Seattle, and New York show noticeably lower percentages of icing in the analyzed altitudes compared to the seven other cities.
- Selected Canadian cities Calgary, Toronto, and Quebec all have an Icing potential of around 20 % and more for the yearly summary.



Overview of the icing conditions in North America – comparing seasonal impact



Frequency of icing conditions per month (%)

- Significant impact of icing from November to March evident for most of the analyzed North American locations.
- For Calgary, Denver, and Seattle, February is the most impacted month by icing.
- For Atlanta rather low percentages for icing can be seen all year around at the considered altitudes.
- In Calgary, the results show only a very short window of 3 months (June, July, and August) where no Icing can be expected.

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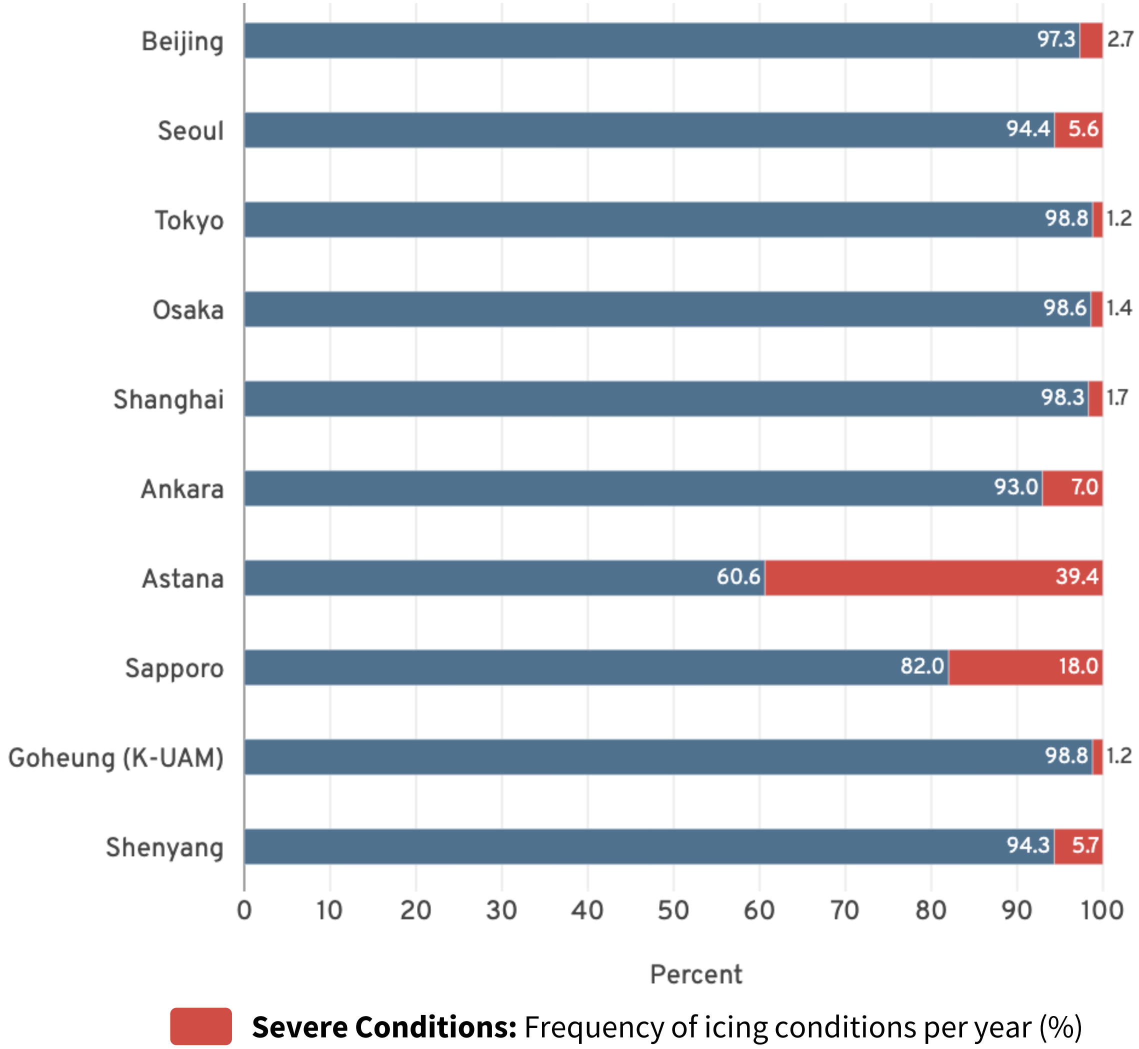
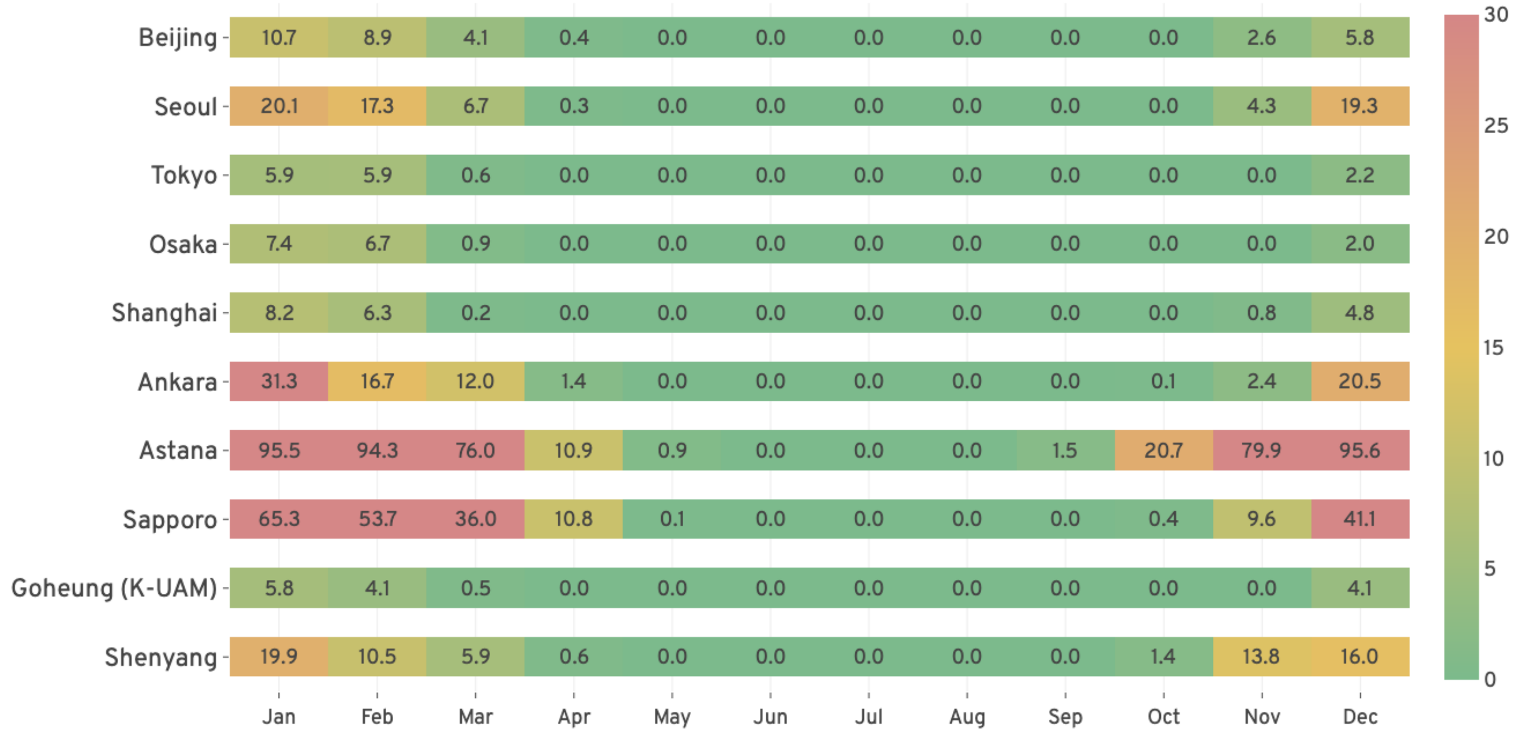
Overview of the icing conditions in Asia – comparing overall impact of icing conditions

- Astana, Sapporo, and Ankara are the most affected cities by icing conditions for the selected ten locations in Asia.
- Astana is also most impacted by icing considering all 30 globally analyzed cities. Around 40% of the yearly hours have a potential for icing conditions.
- Strong differences are remarkable for the icing frequencies in Japan depending on the region.
- While Sapporo in the North indicates considerably high percentages over the year, the frequencies further south at Tokyo and Osaka are significantly lower.



Overview of the icing conditions in Asia – comparing seasonal impact



Frequency of icing conditions per month (%)

- Most Asian cities analyzed have low chances for icing from April to October.
- December, January, and February are most affected by icing for the selected ten locations in Asia.
- Astana has very high frequencies for icing conditions from November to March.
- In Sapporo exists a potential for icing about half of the year.

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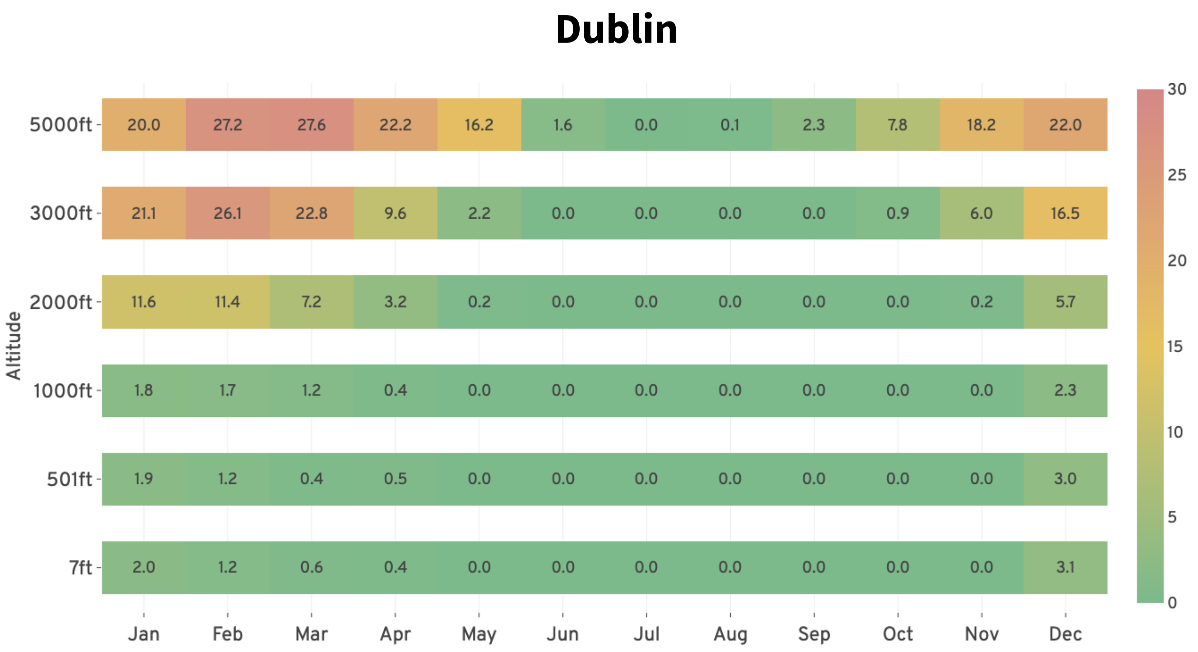
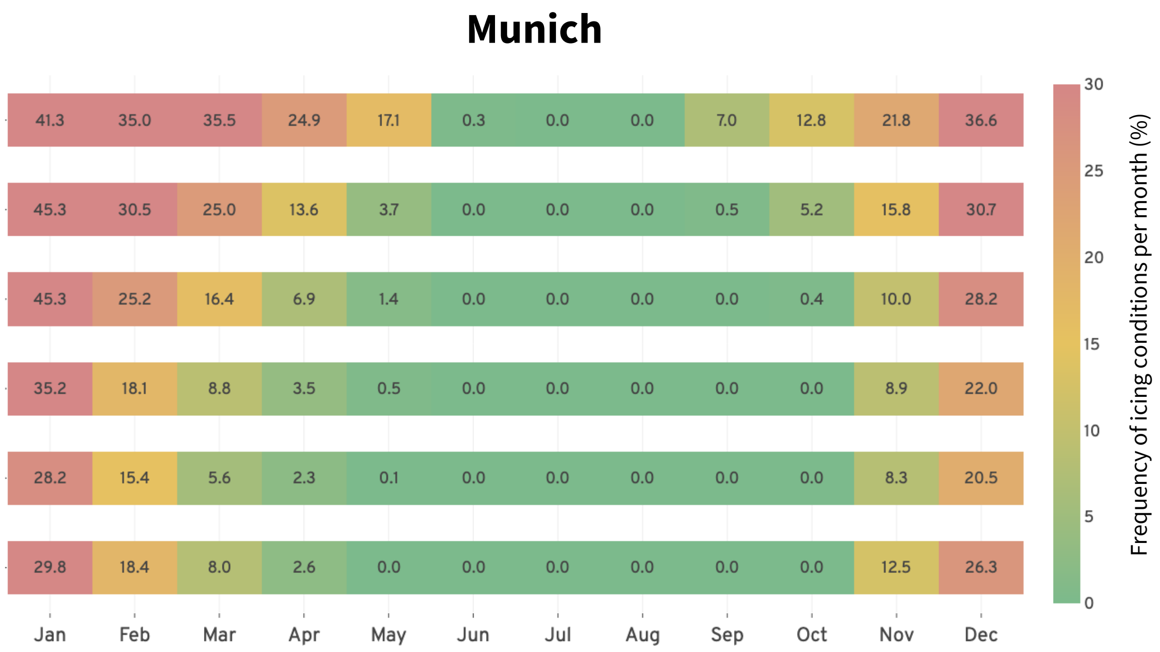
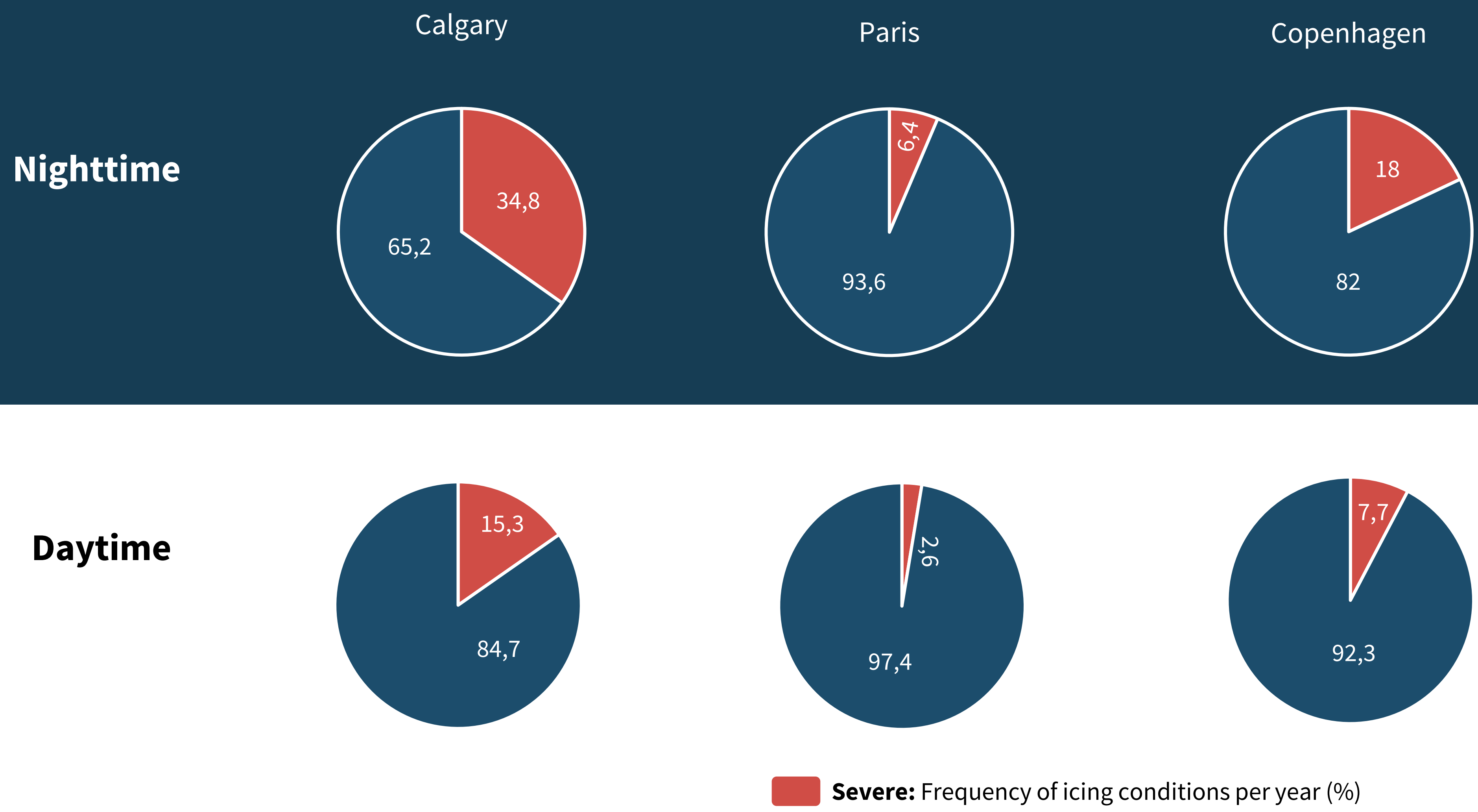
Detail analysis – altitude cross-section





- Dublin shows rather low frequencies of icing at lower altitudes all year around, but towards altitudes above 2000 ft they **increase sharply**.
- The **peak frequency** for the considered altitudes can be found in **March** at 5000 ft with around 28%.
- The results from Munich central station give a particularly clear indication of how the **windows without icing** decrease over the months and altitudes.
- Highest frequencies of icing conditions can be found at 2000 and 3000 ft in **January** with around 45%.

Comparison of daytime and nighttime



- Differences up to nearly 20 % between daytime and nighttime icing frequencies over the year are visible for the three cities.
- For the selected locations nighttime is in general more affected by icing.

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Summary and limitations – an overview

Findings

Strong local effects of icing frequencies between analysed locations are visible even on smaller distance scales within countries (e.g., Japan).

The influence of daytime and nighttime must be examined in depth since there can be large differences in icing conditions depending on the site.

Some of the analyzed locations revealed high percentages of icing conditions over several months which results in a **strongly decreased service availability** for aircraft without de-icing systems.

For **Flight route planning** it can be crucial to know the prevailing icing conditions at certain altitudes to avoid hazards. Thus, some locations showed rather good conditions at lower altitudes, but a sharp degradation towards higher levels.

Limitations of the study

- Icing conditions were identified based on the analysis of **temperature (T)** and relative **humidity (RH)** combinations.
- This method represents a **conservative approach** since no droplet size or cloud data was considered. At some points, the more conservative approach might lead to overestimations.
- However, if we look at the current rules for commercial operations, if icing potential is predicted, **no operations are allowed** if the aircraft is not equipped with a **de-icing system**.
- **No continuous analysis** of altitude bands was performed, but only a specific analysis of a certain altitude layer → Possible icing conditions in between the layers are not covered.

Coordinates

Europe

Name City	Railway Station	Latitude (°)	Longitude (°)
Oslo	Oslo Sentralstasjon	59.91116211	10.75052113
London	Charing Cross	51.50821073	-0.124236689
Berlin	Berlin Central Station	52.52527318	13.36943419
Milan	Milano Centrale	45.48697394	9.205716593
Copenhagen	Copenhagen Central Station	55.67289418	12.56494596
Paris	Paris Gare Du Nord	48.88099783	2.357605695
Munich	München Central Station	48.14042439	11.56000873
Madrid	Madrid Puerta de Atocha	40.40516681	-3.688405374
Dublin	Connolly Railway Station	53.35102665	-6.249981901
Helsinki	Helsinky Central Station	60.1719636	24.94144316

North America

Name City	Railway Station	Latitude (°)	Longitude (°)
Calgary	WB City Hall Station	51.0465126	-114.05672
New York	Grand Central Station	40.752778	-73.977222
Seattle	King Street Station	47.5994879	-122.329912
Chicago	Chicago Union Station	41.87869724	-87.64032119
Toronto	Toronto Union Station	43.64546683	-79.3806321
Quebec	Gare du Palais	46.8176135	-71.2138514
Atlanta	Peachtree Station	33.79956105	-84.3918378
Denver	Denver Union Station	39.7533231	-105.0001411
Minneapolis	Union Depot	44.94733895	-93.08597921
Cincinnati	Cincinnati Union Terminal	39.11	-84.537806

Asia

Name City	Railway Station	Latitude (°)	Longitude (°)
Beijing	Beijing Railway Station	39.904599	116.4272331
Seoul	Seoul Station	37.55486993	126.9708228
Tokyo	Tokyo Station	35.6814279	139.7671463
Osaka	Osaka Station City	34.70717387	135.4958312
Shanghai	Shanghai Hongqiao Railway Station	31.19440182	121.3206078
Astana	Astana-Nurly Zhol Station	51.112389	71.531752
Sapporo	Sapporo Station	43.06861	141.35078
Goheung (K-UAM Challenge)	Korea Aerospace Research Institute	34.61236949	127.2087946
Shenyang	Shenyang railway station	41.795	123.394167
Ankara	Ankara Railway Station	39.9364	32.8438